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Exploring Dental Caries and Associated Factors in 3-Year-Old Iranian Children: An Application of Random Forest for Zero-Inflated Poisson Process

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Abstract

Background: Dental caries, caused by bacterial activity leading to tooth decay, has a profound impact on children's quality of life. This study aimed to investigate factors associated with dental caries in 3-year-old Iranian children.

Methods: A cross-sectional study was conducted involving 815 three-year-old children who were referred to healthcare centers in the southern region of Tehran Province, Iran. Truncated random forest, traditional random forest, and a log-linear model were employed, utilizing the number of dental caries (including excess zeros) as the outcome variable. Predictors included sex, tooth brushing, dental flossing, sweet consumption, dental visits, and parental education level.

Results: The log-linear model's rate ratio (RR) indicated that boys were more likely to have at least 1 decayed tooth compared to girls (RR, 1.11). Dental floss usage significantly reduced childhood dental caries (RR, 2.74). Variable importance analysis from 2 random forests identified dental floss usage, dental visits, and the father's educational level as the most impactful factors on childhood caries. Results based on mean squared error (MSE) demonstrated that the truncated random forest (MSE, 0.002) outperformed the log-linear model (MSE, 0.959) and exhibited similar performance to the traditional random forest model (MSE, 0.006).

Conclusion: The truncated random forest model demonstrated superior performance compared to traditional random forest and log-linear models. From a clinical perspective, promoting knowledge and practices related to good oral health habits in parents and their children emerges as a crucial strategy for reducing the risk of childhood caries.

Keywords: Childhood Caries, Random Forests, Zero-Inflated Outcome, Poisson Process

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Introduction

Dental caries, commonly known as tooth decay, stands as one of the prevalent and preventable chronic diseases globally, originating from a complex interplay involving acid-producing tooth-adherent bacteria, fermentable carbohydrates, and various host factors linked to saliva and dental structures (1). Prevalent cases of caries were estimated at

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↑What is "already known" in this topic:
Dental caries is a prevalent issue in children, significantly impacting their quality of life. Factors such as oral hygiene practices, sweet consumption, parental education, and dental visits are known to influence caries prevalence. Previous studies have also examined sex differences in caries occurrence.

→What this article adds:
This study specifically investigates the factors associated with dental caries in 3-year-old Iranian children using advanced statistical methods—including truncated random forest models. It identifies dental floss usage, dental visits, and parental education as critical determinants and highlights the effectiveness of the truncated random forest model in predicting childhood caries.

64.6 million and 62.9 million, respectively, in permanent and deciduous teeth globally, and it also has a global annual incidence of 46.6%. Despite advancements in preventive measures and early diagnosis, dental caries continues to exert a substantial socioeconomic burden on health systems, affecting individuals of all ages, notably in the 3 to 5-year-old age group, where prevalence exceeds 90% (2). According to the World Health Organization (WHO), >500 million children globally suffer from untreated caries in their primary teeth, posing detrimental effects on their overall health and well-being. Moreover, children with dental caries may experience developmental delays, behavioral problems, abscesses, gum disease, and tooth loss (3).

Timely detection of dental caries is imperative for preventing further damage to teeth and gums. Various methods—including visual examination, dental X-rays, laser fluorescence, and electrical resistance measurements—are employed for caries detection (4). Statistical approaches are also employed alongside medical methods in the identification of dental caries.

Numerous studies investigating factors associated with dental decay have traditionally applied statistical methods, ranging from classic univariate approaches to multivariable regression models such as linear and logistic regression (5). In recent years, more advanced statistical methods, such as machine learning algorithms, have also been employed in this area of research. These methods allow for the consideration of nonlinear relationships between variables, providing more accurate predictions for binary outcomes, such as the presence of dental caries, and a more robust evaluation of associated risk factors. Among these machine learning algorithms, the random forest (RF) technique has emerged as a popular choice. This supervised learning approach employs multiple decision trees trained on random data subsets, with their results amalgamated to generate a final prediction. RF not only facilitates accurate predictions but also yields interpretable results (6).

A review of existing literature in this field reveals a scarcity of studies focusing on the related factors of several dental caries in youngsters. Notably, a study in Zhejiang Province, China, highlighted the high frequency of caries in children aged 3 to 5 years old, associating it with factors such as age, body mass index (BMI), duration of sleep, and breastfeeding (7). Another study in 2009 emphasized the notable influence of health behaviors related to children on dental cavities in 3-year-olds, in comparison to the behaviors of their mothers (8). Moreover, existing studies employing statistical methods have not utilized RF with a splitting rule based on zero-truncated Poisson to identify the risk factors linked to childhood dental cavities. Motivated by these observations and considering the appealing features of RF, our study was designed to explore the efficacy of truncated RF for count data and identify related factors to childhood dental caries in Tehran, Iran (9). Also, the accuracy of this new method for identifying associated risk indicators of dental caries was compared with common approaches, such as the Poisson log-linear model and traditional RF.

Methods

Study Design and Participants

This cross-sectional study was carried out on 816 three-year-old children who were referred to healthcare centers in Pishva and Pakdasht cities, located in the southern region of Tehran Province, Iran. All healthcare centers in the Pishva and Pakdasht regions were included in the sampling frame, and children were randomly selected in each center from July to October 2015. The exclusion criteria comprised children with serious systemic disorders, those on prolonged medication, and uncooperative participants unwilling to undergo examinations.

The calculation of the sample size was informed by prior investigations conducted on the Iranian populace, which reported a mean (SD) prevalence of dental caries at 1.9 (2.8). Employing a significance level of 5%, a margin of error of 0.05, and a statistical power of 0.8, a requisite sample size of 816 participants was determined for this study.

Variables

In this study, 2 dentists were trained according to the basic methods of the WHO oral health survey and calibrated clinically using 10 patients in a 2-day workshop. The reliability of measuring dental caries was investigated for both examiners using intra- and inter-examiner consistency tests, which was confirmed for both examiners. A self-reported questionnaire was used to obtain information about the child's oral health status. The questionnaire was divided into 2 sections. The first section consisted of demographic characteristics, such as sex and parental education level, while the second section included items about perceived oral health, dental pain, frequency of dental visits, tooth brushing and flossing, and eating sweets between meals. Dental caries were recorded by examining the child's teeth under natural light using a dental mirror and round-tip periodontal probe, according to the WHO standards.

Statistical Analysis

Frequencies and percentages were utilized to describe qualitative features.

Random Forest

The random forest algorithm, a widely adopted ensemble method, is briefly outlined here with an assumption of reader familiarity. Methods based on tree structures strategically divide the space of covariates through recursive splitting based on rules derived from the features. The central element in tree construction is the splitting criterion, which varies based on the problem under consideration. For instance, the least-squares splitting criterion is commonly used for continuous response variables. When splitting a given node into 2 child nodes, the optimal division is selected from all potential binary divisions derived from a covariate. If the covariate is continuous, the potential divisions are in the format $I(x \leq z)$. If the covariate is categorical, the potential divisions are in the format x $\in \{z_1, ..., z_s\}$, where $\{z_1, ..., z_s\}$ is a subset of the potential x values. The optimal division is determined by maximizing the criteria for splitting. While a decision tree can be constructed by building a large tree and pruning it, it has been shown

that utilizing a combination of trees is generally favored. In this context, the random forest method is usually considered one of the most popular ensemble approaches in the literature. This method involves drawing B resampled datasets of the original data and constructing a tree using a chosen splitting criterion for each resampled dataset. At each node, q_0 out of q covariates are randomly selected, and splitting ceases when a stopping criterion is reached. To obtain an estimation for a parameter or make a prediction for a new observation, the calculated averages of estimates or predictions from the B trees are utilized (10).

Truncated Random Forest

In this study, the main outcome is the number of dental caries, which is a count variable with a significant prevalence of zero values. To address this characteristic, an RF is constructed utilizing the count of tooth decay in children aged 3 years, specifically targeting instances with a high proportion of zero values. The predictors encompass sex, tooth brushing habits, dental flossing practices, sweet consumption patterns, dental visit history, and parental education levels. Regarding this, we utilized a newly introduced approach by Mathlouthi et al, which enables us to handle the Poisson processes with the inflation of zeros. The new method applies the forest, called "truncated model or truncated RF" that can be achieved by fitting a random forest to the positive observations only (9).

For the truncated model, the forest was constructed using a splitting criterion derived from the likelihood of zero-truncated Poisson distribution:

$$p(Y = y|Y > 0) = \frac{exp(-\lambda)\lambda^y}{\big(1 - exp(-\lambda)\big)y!}$$

Where λ is the parameter of Poisson distribution and y is the number of dental caries. The optimal split at a given node is determined by maximizing the likelihood of the zero-truncated Poisson distribution (9).

Traditional Random Forest

In the conventional framework of RFs (referred to as the traditional method), the typical splitting rule relies on minimizing the sum of squared errors or maximizing information gain. However, the proposed methodology uses a specialized splitting rule for the truncated Poisson part of the random forests (8).

Variable Importance

Variable importance is a key output of RF models, as it measures the strength of the relationship between a given variable and the outcome. In this study, the permutation importance index was used to calculate variable importance. This index can be estimated using randomly permuting the out-of-bag (OOB) data for a variable and observing the resulting change in prediction error. This process is iterated for every tree within the RF model. The concept suggests that important variables show a greater impact on prediction performance when their values are randomly permuted compared to unimportant variables (11).

Poisson Log-Linear Model

We also fit the Poisson log-linear model as a common parametric technique. This model makes predictions based on o variables that influence the count data, under the assumption that the data follows a Poisson distribution. The model uses a logarithmic transformation to linearize the relationship between the predictor variables and the expected count, adjusting for other confounders (12). The significance level was set at 0.05.

Model Evaluation

The accuracy of methods in the study is evaluated using the MSE. To determine the MSE, we utilized a method that involves aggregating observations into similar groups to estimate λ, given the availability of groups with identical covariates' values. Assuming the objective is to create groups of size n, the following steps are followed:

1. Calculate the first principal component of the observations by considering all covariates.
2. Arrange the observations based on the magnitude of the first principal component.
3. Create groups using the ranking process. Specifically, the first group (G1) consists of the n observations with the lowest values of the first principal component. Similarly, the second group (G2) is comprised of the next m observations with the smallest values of the first principal component, and this pattern continues for subsequent groups. This procedure ensures that every observation is assigned to a group.
4. Once the groups are established, it becomes possible to compute the true group parameter values for each group using the Poisson model.
5. By employing this approach, we can effectively estimate λ while organizing observations into distinct groups that share similar characteristics based on the covariates utilized. These estimates are then considered as the assumed true parameter values (9).

The descriptive and univariate analyses were performed using the SPSS software Version 27.0. In addition, to fit the random forest model, we utilized the RandomForestSRC package in R Version 4.2.2. We opted to use the default settings, which involve analyzing 1000 trees and the number of variables examined at each node when determining the optimal split at each node.

Results

In this study, the data from a total sample of 815 three-year-old children with 362 (44.4%) being free of caries was analyzed. Among them, 398 (48.8%) were male and 417 (51.2%) were female (Table 1).

In the next step, we fitted a multivariable Poisson log-linear model to investigate the concurrent effect of explanatory factors on several dental caries. The results of this analysis are presented in Table 2. Regarding the reported estimates in this table, one can observe that all of the predictors had a significant association with the outcome variable ($P < 0.05$). The obtained estimates in this model can be interpreted in terms of rate ratios (RR) reported in the Exp(B) column. For instance, the estimated RR of 1.11 for

Table 1. General characteristics of the sample

Variable	Category	N (%)
Gender	Male	398 (48.8)
	Female	417 (51.2)
Flossing	Once or more than once a day	585 (71.8)
	Never	228 (28.0)
Brushing	Never	453 (55.6)
	Once or more than once a day	347 (42.6)
Dental visit	Yes	138 (16.9)
	No	667 (81.8)
Consumption of sweets	Once	372 (45.6)
	More than once a day	438 (53.7)
Father's educational level	High school and above	687 (84.3)
	Lower than high school	126 (15.5)
Mother's educational level	High school and above	693 (85.0)
	Lower than high school	119 (14.6)

Table 2. Poisson log-linear modeling results of factors associated with dental caries

Variable	Category	B	SE	Exp(B)*	*P*- value
Gender	Male	0.107	0.044	1.113	<0.01
	Female			Reference	
Brushing	Once or more than once a day	-0.117	0.045	0.889	<0.01
	never			Reference	
Flossing	never	1.01	0.189	2.740	<0.001
	Once or more than once a day			Reference	
Dental visit	Yes	0.711	0.049	2.036	<0.001
	No			Reference	
Consumption of sweets	More than once a day	0.117	0.045	1.125	<0.001
	Once			Reference	
Father's educational level	Lower than high school	0.226	0.073	1.253	<0.001
	High school and above			Reference	
Mother's educational level	High school and above	-0.204	0.079	0.815	<0.01
	Lower than high school			Reference	

*Rate ratio

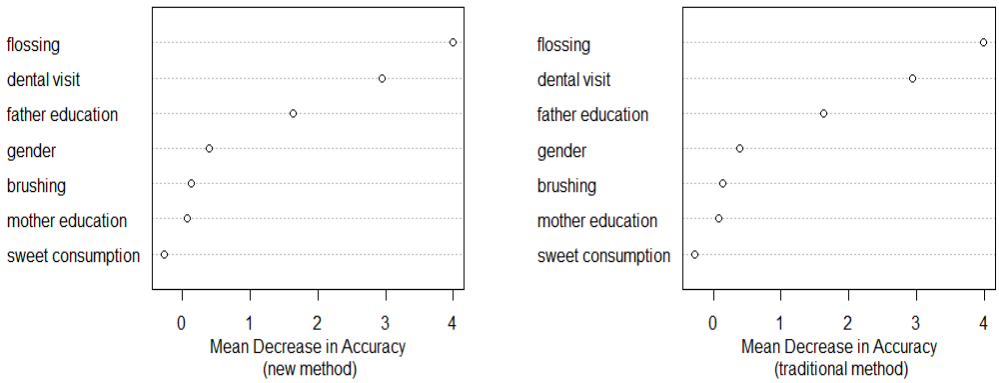

Figure 1. Variable importance of Random Forest model for predicting dental caries in 3-year-old Iranian children

the sex variable signifies that the rate of dental caries in boys was approximately 11% higher than in girls.

In the third phase of data analysis, we applied 2 distinct random forest models (traditional and truncated random forests) to the subset of data representing children with at least 1 dental caries. The importance indices for various predictors under consideration are depicted in Figure 1. Regarding the obtained findings from both methods, we can conclude that the use of dental floss, having dental visits and father's educational level were, respectively, the predictors with the most important effect on the number of childhood caries. The estimated MSE for log-linear, traditional random forest, and truncated random forest models was, respectively, 0.959, 0.006, and 0.002.

Discussion

Dental caries, instigated by acid-producing bacteria in the oral cavity, stands as a prevalent oral health concern among children. Despite our comprehensive understanding of the profound impact of dental caries on the lives of children, there remains a paucity of studies investigating the determinants of dental caries in 3-year-olds. Moreover, existing studies in this domain often neglect to adequately account for caries-free cases in their statistical analyses. In our study, addressing the challenge posed by an excess of zeros in the data, we undertook an examination of factors associated with dental caries through the application of the Poisson log-linear model, traditional random forest, and truncated random forest model. According to our findings, all applied models had good performances in terms of MSE. However, the performance of the truncated random forest model was better than other approaches. Also, the results of the variable importance analysis based on the truncated random forest model indicated that dental floss and visits have higher relative importance than other indicators. Subsequently, the father's educational level and sex have considerable contributions to the prediction of dental caries. These findings are consistent with those important variables identified in the multiple Poisson log-linear and the traditional random forest models.

In this study, we systematically evaluated the impact of various factors on childhood dental caries, categorizing them into 2 distinct groups. The first category comprised demographic characteristics such as sex, age, and parental educational level, while the second category encompassed oral behavior factors such as using dental floss, frequency of dental visits, sweet consumption habits, and frequency of brushing.

Our associated findings with demographic factors revealed that boys exhibited a higher rate of dental caries, with the rate of tooth decay in boys being 1.11 times higher than in girls. Additionally, we observed that the educational level of parents played a crucial role in a child's oral health, with higher parental education contributing collectively to lower childhood dental caries. However, fathers' education showed a more remarkable effect on children's tooth decay compared to mothers. This might be because highly educated fathers are more likely to have better occupational status and higher income with wider health insurance coverage in traditional Iranian families. This can contribute to improved access to dental healthcare services, which reduces the likelihood of experiencing childhood caries. Our results are in line with the findings of the research conducted by Dumitrescu et al and Saldūnaitė et al. In the study conducted by Dumitrescu et al on 814 schoolchildren in Romania, a significant negative correlation was reported between father's educational level and dental caries, meaning that higher levels of father's education are related to lower occurrence of dental caries in children (13). An Italian study by Saldūnaitė et al showed that parents with higher education levels possess greater awareness and understanding of the significance of preventive dental care, which results in improving oral hygiene (14). Regarding the sex factor, the findings of the research by Saravanan et al indicated that a higher percentage of 5-year-old boys had dental caries compared to girls. More explicitly, 47.4% and 41.1% of boys and girls, respectively, had dental caries. They, however, demonstrated a higher percentage of female children with dental caries compared to male children in the 12-year-old age group (15).

Moving on to the second category of features (oral behavior factors), we delved into factors related to oral behavior. In this context, our statistical analysis revealed 2 main findings; first, children who did not use dental floss had a substantially elevated rate of dental caries compared to those who used dental floss at least once a day. This aligns with the findings of a systematic review by Hujoel et al, wherein controlled clinical trials showed a reverse association between flossing and the occurrence of tooth decay. They reported that regular professional flossing done by first-grade schoolchildren lowered the likelihood of dental caries by 40%, particularly among children who have inadequate oral hygiene practices and limited exposure to fluoride (16). In another study by Ghasemianpour et al, they declared that although no correlation was found between the usage of dental floss and the prevalence of dental caries among children aged 12 years, 6-year-old children who used dental floss experienced a decreased likelihood of developing tooth decay compared to the others. Second, we found a reverse association between the frequency of dental cavities and dental visits. To justify this surprising finding, we should explain that referring to dentists for regular dental check-ups is not common in Iranian families, especially in this age group. While regular dental appointments play a crucial role in preserving oral health and preventing dental caries, many Iranian parents generally tend to visit dentists when their children experience pain or notice signs of dental decay. Our results about dental visits are supported by the results of 2 other studies. In the study carried out by Beil et al, it was shown that children requiring care due to known oral health problems or discomfort were more inclined to seek dental care promptly and receive early treatment (17).

In the current study, we used advanced statistical approaches to identify factors associated with childhood caries. We applied random forest models with different split rules. The first approach was a traditional random forest utilizing the least-squares splitting rule, and the second one was a newly proposed random forest employing customized splitting criteria formulated based on the zero truncated Poisson likelihood (9). At the same time, numerous predictors are statistically related to tooth decay. Maternal oral health, socioeconomic backgrounds, fluoride exposure, genetic factors, and bottle-feeding habits are some of the other risk indicators of tooth decay in pediatric individuals. Ignoring the simultaneous effect of the described factors on childhood caries was the foremost limitation of our study.

There are specific limitations that warrant consideration in this study. Due to the cross-sectional design of the study, it is not possible to establish a cause-and-effect relationship between the predictors identified and dental caries. The investigation of temporal relationships might be strengthened by longitudinal research. Additionally, recall bias may be introduced due to the reliance on self-reported questionnaires to collect data on certain variables, including dental

pain and oral health status. Subsequent investigations might be enhanced by the incorporation of objective metrics or a hybrid approach combining self-report and clinical evaluations. Moreover, while the paper addresses the excess of zero values in dental caries data using the truncated random forest model, the study does not explore potential interactions between predictors, which might contribute to a more nuanced understanding of dental caries determinants. Mitigation strategies include incorporating longitudinal designs, employing objective measures, and exploring interactions among predictors to enhance the study's robustness and contribute more effectively to the existing knowledge on childhood dental caries.

Conclusion

Using machine learning approaches, such as the truncated random forest model, challenges the inaccurate predictions caused by excess zeros, as well as the complexity and interactions between variables. By minimizing these issues, this algorithm can effectively identify children who are susceptible to developing dental cavities. Clinically, we found that several demographic and oral health behaviors are significant indicators of childhood dental caries. The identified demographic features are out of clinicians' control; thus, it seems that providing good oral health behavior training to parents and children remains the key point in preventing childhood dental caries.

Authors' Contributions

Fatemeh Masaebi contributed to the conceptualization, data collection, and original draft preparation of the manuscript.

Masoud Salehi and Mehdi Azizmohamadlooha were responsible for the methodology development and statistical analysis.

Zahra Ghorbani and Morteza Mohammadzadeh contributed to the data interpretation and critical revision of the manuscript.

Marzie Deghatipour and Denis Larocque provided technical support and contributed to the final editing of the manuscript.

Farid Zayeri, as the corresponding author, supervised the entire project, provided guidance throughout the research process, and approved the final version of the manuscript.

Ethical Considerations

The study was approved by the ethics committee of Shahid Beheshti University of Medical Sciences (Ethics code: IR.SBMU.RETECH.REC.1402.137).

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Declared none.

Conflict of Interests

The authors declare that they have no competing interests.

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